DETERMINATION OF SIZE OF SERVICE OR SECONDARY CONDUCTOR TO PREVENT FLICKER

by
S. Lubin
Associate Engineer, Technical Standards Division

U. S. DEPARTMENT OF AGRICULTURE
RURAL ELECTRIFICATION ADMINISTRATION
TECHNICAL STANDARDS DIVISION

Technical Standards Bulletin #2
July 24, 1941

SUMMARY

The selection of sufficiently large secondary or service conductors will eliminate flicker due to excessive voltage drop in these conductors when motor loads are switched into the circuit. The method outlined in this bulletin allows the determination of the minimum size of conductor when certain factors are known.

DETERMINATION OF SIZE OF SERVICE OR
SECONDARY CONDUCTOR TO PREVENT FLICKER

The following considerations should be taken into account in using the attached charts:

1. The values obtained from the charts are valid provided the primary regulation is sufficient to take care of the starting current. In cases where primary regulation is poor, the value of secondary supply voltage used should take into account primary voltage drop due to the starting current.

2. Since in some cases this method would require the use of service conductors or transformers of larger sizes than is usual in REA usage, some judgment should be used in its application. It should be applied only where motor loads are coincident with lighting.

3. When a current-limiting starting device is used, the value of starting current used in the calculations should be the value as limited by the starting device. A table of average starting currents and starting power factors of various types of motors is attached to this bulletin. This contains average values of motors as listed by several manufacturers and is useful when more precise data is not available.

USE OF THE CHARTS

The following information must be on hand before the secondary size can be determined from the attached charts:

1. Number of starts per hour, minute, or second, of the motor.

2. Make and size of transformer to be used.

3. The supply voltage (E) on the secondary or service.

4. The starting current (I) of the motor.

5. Power factor of the motor at starting (cos 0).

6. Length of secondary or service circuit (L).

The general procedure is then as follows:

1. Determine the allowable percent of voltage fluctuation from Chart I.

2. Determine the percent R and percent X of the transformer from Chart II.

3. Convert the allowable percent voltage fluctuation from the transformer rating basis to the actual load basis by use of Chart III.

4. Determine the percent voltage drop in the transformer and the percent resistance drop in the secondary or service conductor from Chart IV.

5. Obtain the required conductor size or resistance in ohms per 1000 feet from Chart V.

Detailed steps are given in the following pages with each chart.

AVERAGE LINE STARTING CURRENTS AND STARTING POWER FACTORS OF MOTORS

Single-Phase

HP	Line Starting Current (Amps.)	Starting Power Factor
Condenser Start 110 Volts		
1/6	22	.75
1/4	23	.75
1/3	23	.75
220 Volts		
1/3	12	.75
1/2	16	.75
3/4	23	.75
1	30	.75
Split Phase 110 Volts		
1/8	17	.65
1/6	28	.65
1/4	29	.65
1/3	30	.65
1/2	37	.65
3/4	60	.65

HP	Line Starting Current (Amps.)	Starting Power Factor
Repulsion-Induction 110-Volts		
1/8	13	.50
1/6	13	.50
1/4	14	.50
1/3	19	.50
1/2	26	.50
3/4	38	.50
220 Volts		
1/2	14	.50
3/4	20	.50
1	25	.50
1-1/2	34	.50
2	41	.50
3	58	.50
5	95	.50
7-1/2	150	.50

Three-Phase

Squirrel Cage 110 Volts		
1/2	19	.11
3/4	29	.16
1	41	.10
1-1/2	58	.10
2	72	.11
3	105	.12
5	165	.12
7-1/2	235	.13
10	300	.13
15	415	.14
20	490	.15
25	660	.15
30	775	.15
40	1110	.14
50	1370	.14
60	1650	.14
75	2010	.15
100	2940	.14
125	3380	.15
150	4610	.13
200	6580	.12
250	7300	.14
208 Volts		
3	37	.12
5	88	.12
7-1/2	115	.13
10	155	.13
15	225	.14
20	285	.15
25	360	.15
30	410	.15
40	530	.14
50	715	.14

Three Phase

HP	Line Starting Current (Amps.)	Starting Power Factor
Squirrel Cage 220 Volts		
1/8	3.7	.10
1/6	4.6	.10
1/4	6.4	.10
1/3	9.6	.10
1/2	10	.11
3/4	15	.16
1	21	.10
1-1/2	31	.10
2	38	.11
3	52	.12
5	82	.12
7-1/2	120	.13
10	150	.13
15	220	.14
20	275	.15
25	355	.15
30	415	.15
40	555	.14
50	690	.14
60	865	.14
75	1050	.14
100	1500	.14
125	1800	.13
150	2390	.13
200	3290	.12
250	3650	.12
440 Volts		
1/2	4.8	.11
3/4	7.1	.16
1	10	.10
1-1/2	15	.10
2	18	.11
3	25	.12
5	41	.12
7-1/2	57	.13
10	74	.13
15	105	.14
20	130	.15
25	165	.15
30	190	.15
40	275	.14
50	345	.14
60	410	.14
75	500	.14
100	735	.14

HP	Line Starting Current (Amps.)	Starting Power Factor
125	845	.14
150	1155	.13
200	1635	.12
250	1825	.12
550 Volts		
1/2	3.8	.11
3/4	5.7	.16
1	7.9	.10
1-1/2	13	.11
2	15	.11
3	20	.12
5	36	.12
7-1/2	46	.12
10	59	.13
15	84	.14
20	105	.15
25	135	.15
30	155	.15
40	220	.14
50	290	.14
60	340	.14
75	395	.14
100	590	.14
125	675	.14
150	920	.13
200	1320	.12
250	1460	.12
2200 Volts		
30	40	.15
40	55	.14
50	68	.14
60	95	.14
75	110	.14
100	150	.14
125	195	.14
150	255	.14
200	295	.14
250	365	.14
300	475	.12

CHART I

ALLOWABLE PERCENT OF VOLTAGE FLUCTUATION

This chart shows the permissible percent of voltage fluctuation for a varying number of fluctuations (or motor starts) per unit time.

Example: A three phase $7\frac{1}{2}$ H.P. 220 Volt motor starts 6 times per hour.

Against 6 fluctuations per hour on the curve read 3.6% allowable voltage fluctuation.

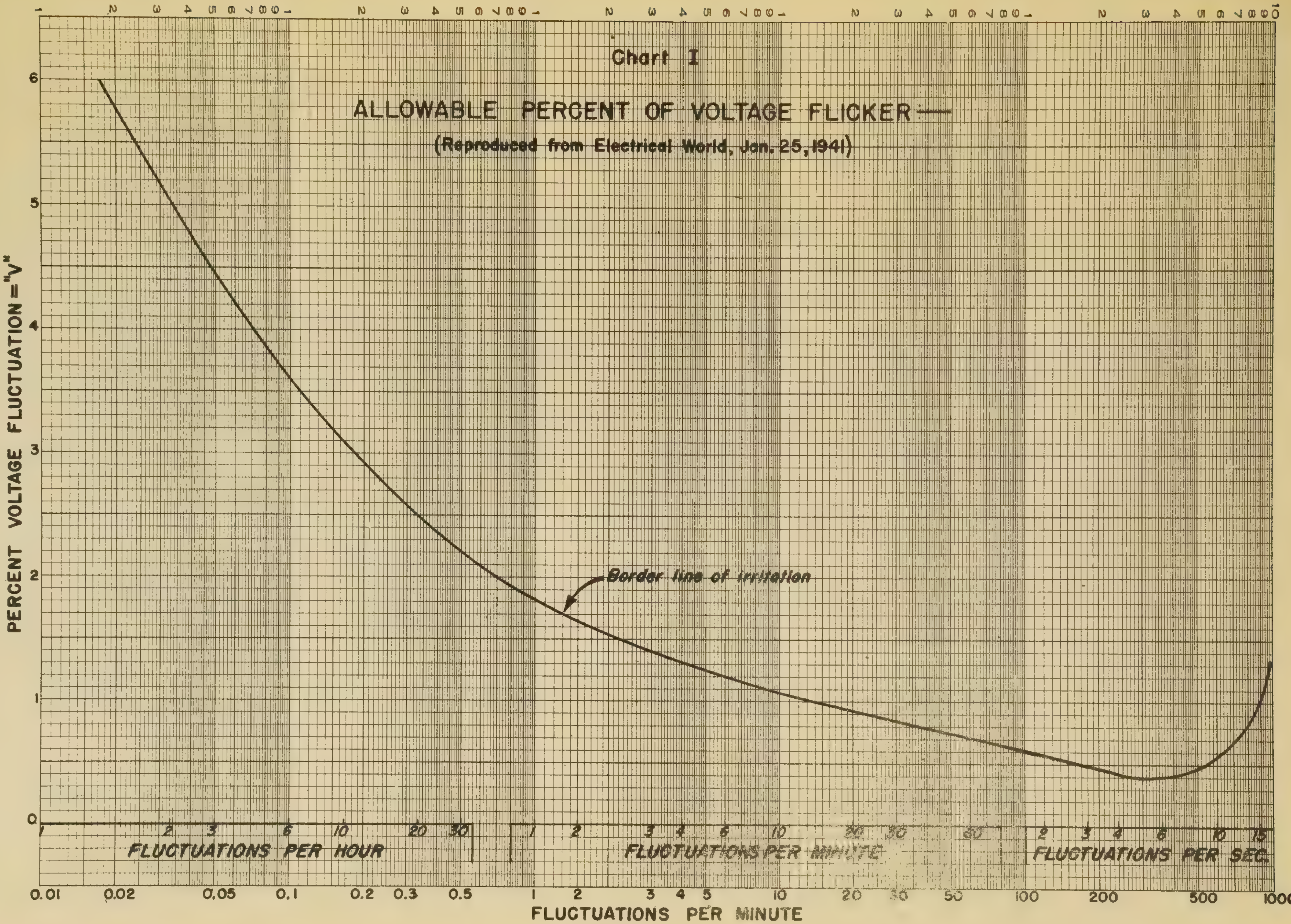


Chart I
ALLOWABLE PERCENT OF VOLTAGE FLICKER —
(Reproduced from Electrical World, Jan. 25, 1941)
Border line of irritation
PERCENT VOLTAGE FLUCTUATION = "V"
FLUCTUATIONS PER HOUR
FLUCTUATIONS PER MINUTE
FLUCTUATIONS PER SEC.
FLUCTUATIONS PER MINUTE

Chart II

PERCENT RESISTANCE AND PERCENT REACTANCE OF DISTRIBUTION TRANSFORMERS*

TRANSFORMER RATING (KVA.)	ALLIS CHALMERS		GENERAL ELECTRIC		KUHLMAN		LINE MATERIAL		MOLONEY		STANDARD		WAGNER		WESTING-HOUSE	
	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T	% R_T	% X_T
1.5	2.37	2.08	2.60	2.19	2.86	1.67	3.06	1.48	2.73	1.67	3.06	1.90	2.25	1.31	2.87	0.88
3	2.08	2.04	2.27	2.24	2.46	1.60	2.73	1.80	2.40	1.80	2.80	1.50	2.26	1.80	2.26	1.96
5	2.25	1.79	2.20	2.18	2.22	1.91	2.50	1.99	2.42	2.10	2.57	2.44	2.20	1.99	2.00	1.32
7.5	2.00	2.21	2.15	1.79	2.27	2.33	2.27	2.25	2.27	2.34	2.33	1.72	1.81	1.69	2.08	1.88
10	1.85	2.25	2.00	1.96	2.17	2.63	2.17	2.36	2.02	2.26	1.95	2.34	1.83	2.11	1.90	1.63
15	1.53	2.24	1.72	2.21	1.78	2.82	1.78	2.66	1.82	2.87	1.82	2.48	1.65	2.29	1.68	1.85
25	1.42	2.57	1.51	2.36	1.60	3.19	1.60	2.78	1.53	3.14	1.67	2.90	1.36	2.88	1.47	2.73
37.5	1.32	2.79	1.31	2.47	1.38	3.61	1.38	2.89	1.35	2.90	1.49	2.80	1.20	2.88	1.39	3.03
50	1.16	2.91	1.22	2.52	1.04	3.80	1.34	2.91	1.38	2.96	1.34	2.90	1.08	3.30	1.29	3.37
75	1.09	2.64	1.10	2.47	1.25	3.36	1.25	4.84	1.31	3.10	1.21	3.68	1.16	3.44	1.20	4.80
100	1.13	3.07	1.12	2.46	1.23	3.46	1.23	4.84	1.24	3.10	1.26	3.80	1.07	4.41	1.22	3.96

*Rating from 1.5 Kva. to 15 Kva. inclusive are R.E.A. type. Rating of 25 Kva. and above are conventional double bushing type.

CHART III

TO CONVERT ALLOWABLE PERCENT VOLTAGE FLUCTUATION
from
TRANSFORMER RATING BASE TO ACTUAL LOAD BASE

1. Use value of V from Chart I.

2. Connect V and W. Mark intersection on A.

3. Proceed from A to E. Mark intersection on W.

4. Connect W and I. Intersection on Z is allowable percent voltage fluctuation under actual load conditions.

Example: 3 - 3 Kva Kuhlman transformers are used to serve the motor in the previous example. The line starting current (from the table of starting current) is 120 amps. The phase current I is equal to $1/3 \times 120 = 40$ amps.

1. Connect V = 3.6% with W = 3 Kva. Mark intersection on A.

2. Proceed from A to E = 220/1.73 = 127 volts, phase to neutral. Mark intersection on W.

3. Connect W and I = 40 amps. Then Z = 2.0%.

Z = Percent regulation in transformer and conductors.
V = Allowable voltage fluctuation in percent *(from Chart I)*.
W = Kva rating of transformer.
I = Motor starting current.
E = Supply voltage $\begin{cases} 1\phi = \textit{Voltage between conductors.} \\ 3\phi = \textit{Phase to neutral voltage = Phase to phase voltage divided by 1.73} \end{cases}$

Chart III

To Find Z

1. Connect V and W. Mark intersection on A.
2. Connect A and E. Mark intersection on W.
3. Connect intersection on W with I. Read value on Z.

EQUATIONS of CHART

$$Z = \frac{1000\ V\ W}{I\ E}$$

B = ZI (B coincident with W)

A = BE

A = V (1000 W)

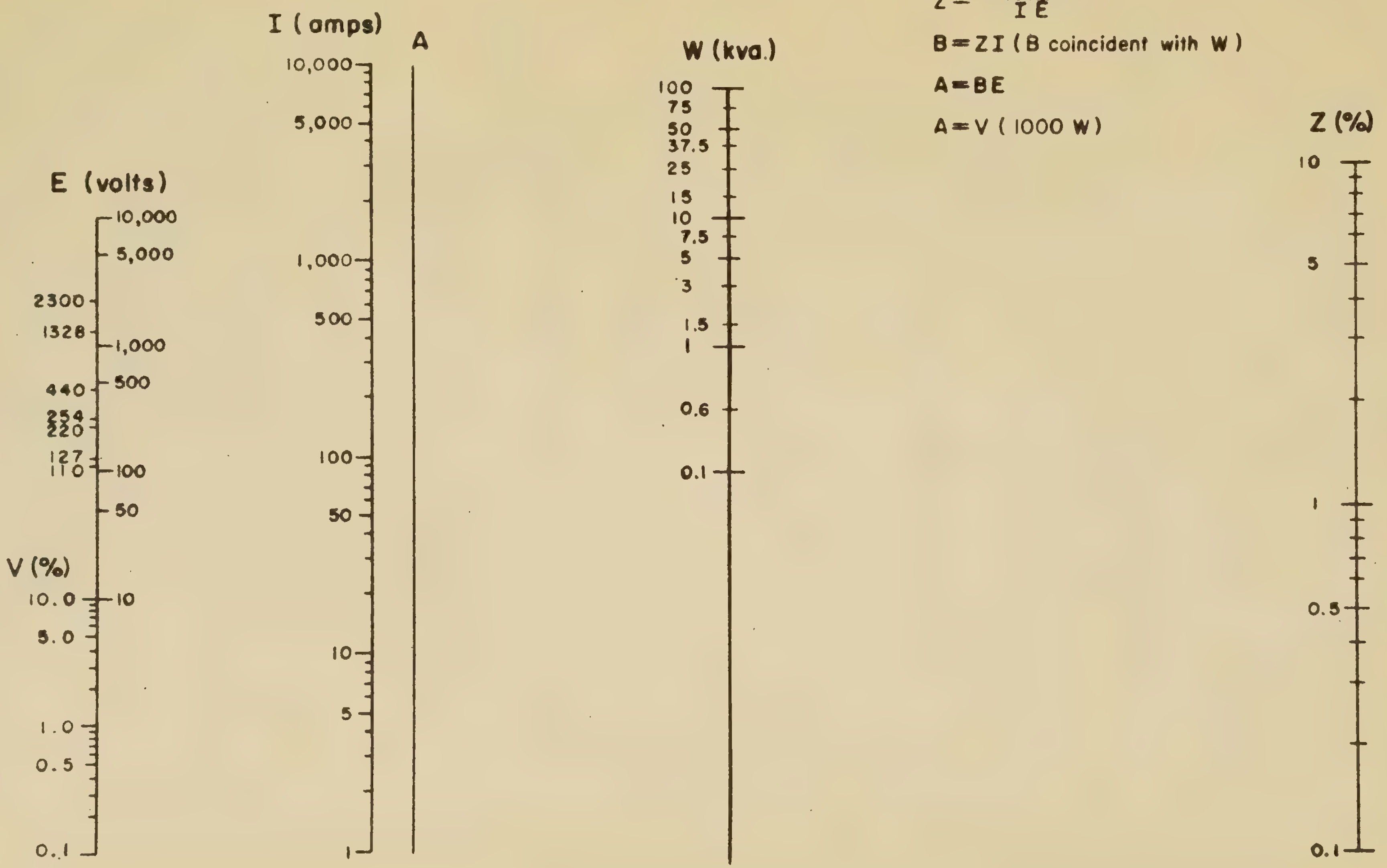


CHART IV

(a). To Determine Percent Voltage Drop in Transformer

1. Use values of R_T and X_T from Chart II.

2. Connect R_T and Power Factor. Read value of intersection on C.

3. Connect X_T and Power Factor. Read value of intersection on D.

4. Percent Voltage drop in transformer: $Z_T = C + D$.

5. Percent Voltage drop in secondary: $Z_s = Z - Z_T$.

(b). To Determine Percent Resistance Drop in Secondary or Service Circuit.

1. Connect Z_s and Power Factor

2. Intersection on R_s is percent resistance drop in secondary or service circuit.

Example: (a) From Chart II, for the transformer in the previous example, $R_T = 2.46\%$, $X_T = 1.60\%$. Starting power factor for the motor, from Table of Starting Currents and Power factors, is 0.13.

1. Connect $R_T = 2.46\%$ and Power Factor. Read 0.3% on C.

2. Connect $X_T = 1.60$ and Power Factor. Read 1.4% on D.

3. $Z_T = 1.4 + 0.3 = 1.7\%$.

4. $Z_s = 2.0 - 1.7 = 0.3\%$.

(b)

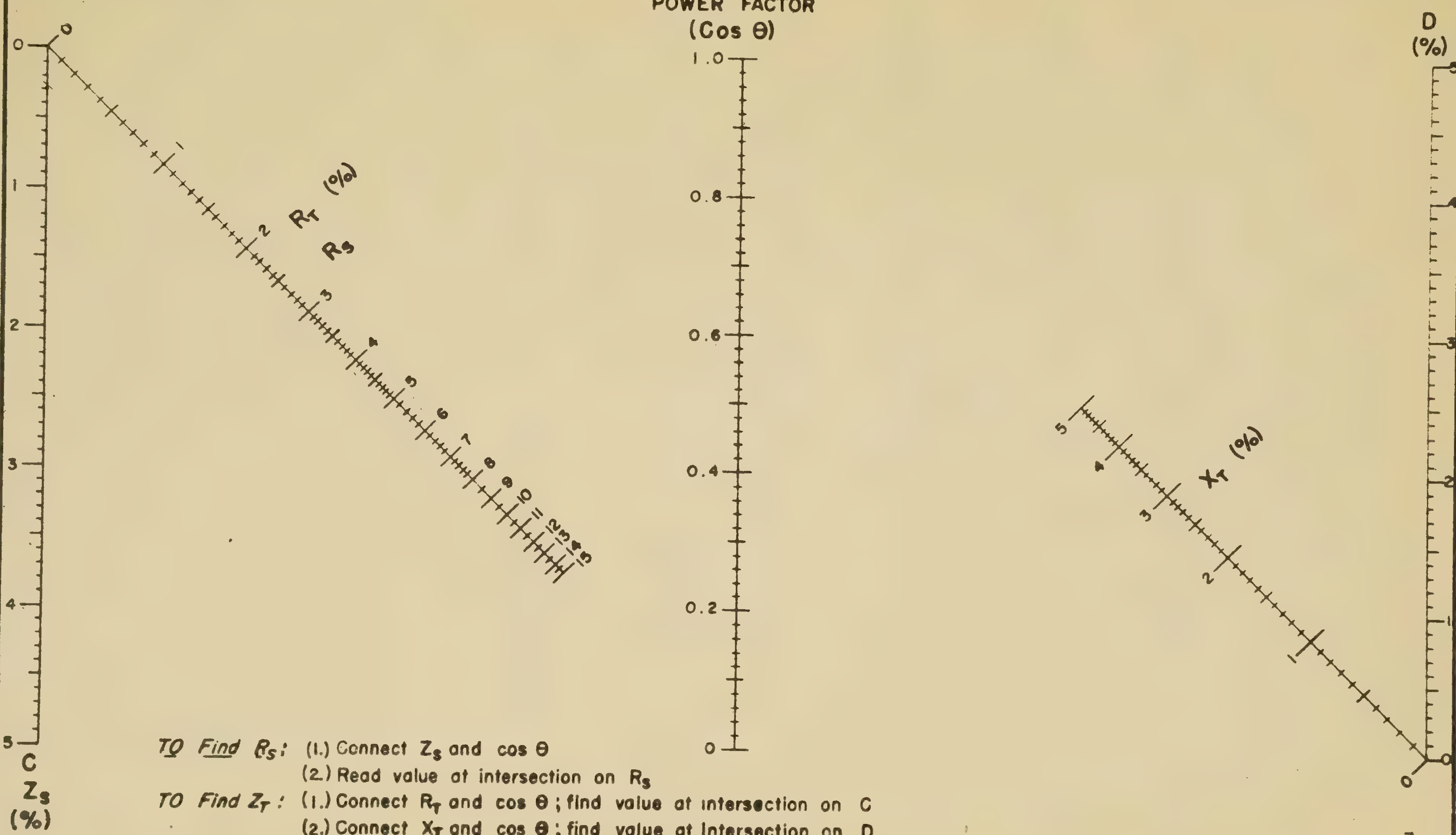
1. Connect $Z_s = 0.3\%$ and Power Factor. Read $R_s = 2.4\%$.

R_T = % Resistance of transformer
X_T = % Reactance of transformer
θ = Power factor angle of motor at starting
Z_T = % Regulation of transformer
Z_S = % Regulation of service circuit
R_S = % Resistance drop of service circuit

—Chart IV—

EQUATIONS of CHART

1. $C = R_T \cos \theta$
   $D = X_T \sin \theta$
   $Z_T = C + D$
2. $Z_S = R_S \cos \theta$



TO Find R_S: (1.) Connect Z_S and $\cos \theta$
(2.) Read value at intersection on R_S

TO Find Z_T: (1.) Connect R_T and $\cos \theta$; find value at intersection on C
(2.) Connect X_T and $\cos \theta$; find value at Intersection on D
(3.) $Z_T = C + D$

CHART V

TO DETERMINE SECONDARY OR SERVICE CONDUCTOR SIZE

1. Connect R_s and E. Mark intersection on F.
2. Proceed from F to I. Mark intersection on R_s.
3. Connect R_s and L. Mark intersection on "r".
4. Intersection on "r" shows resistance of conductor in ohms per 1000 ft. or copper equivalent.

Example: Length of service L = 100 feet.

1. Connect R_s = 2.4% and E = 127 volts. Mark intersection on F.
2. Proceed from F to I = 40 amps. Mark intersection on R_s.
3. Connect R_s and L = 100 ft.
4. r = 0.8 ohms/1000 ft. or No. 8 copper equivalent can be used.

SHEET 7

TO DETERMINE RESISTANCE OF SERVICE CONDUCTOR SIZE

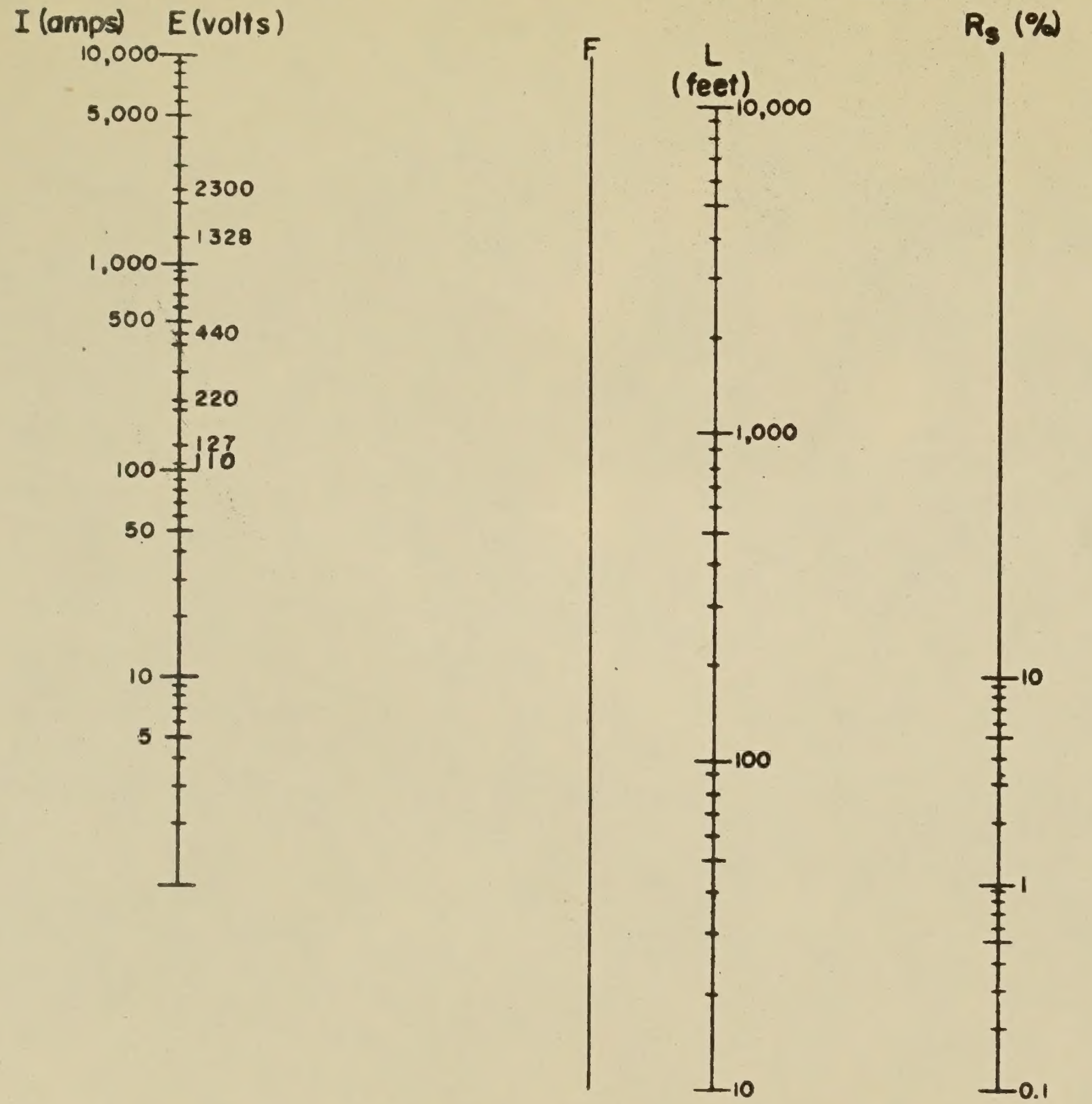
1. Connect E_s and E. Mark intersection on P.
2. Proceed from P to I. Mark intersection on R_s.
3. Connect R_s and L. Mark intersection on "r".
4. Intersection on "r" shows resistance of conductor in ohms per 1000 ft. or copper equivalent.

Example: Length of service L = 100 feet.

1. Connect E_s = 2.4% and E = 117 volts. Mark intersection on P.
2. Proceed from P to I = 40 amps. Mark intersection on R_s.
3. Connect R_s and L = 100 ft.
4. r = 0.8 ohms/1000 ft. or No. 8 copper equivalent can be used.

R_s = Percent resistance drop in service conductor.
r = Resistance of service conductor (OHMS/1000 FT.)
L = Length of service circuit (FEET) { *1ϕ = 2 x length of one conductor.* / *3ϕ = Length of one conductor.*
I = Motor starting current.
E = Supply voltage { *1ϕ = Voltage between conductors* / *3ϕ = Phase to neutral voltage = Phase to phase voltage* ***divided*** *by 1.73*

— Chart V —



TO Find Size of Service Conductor:—

1. Connect R_s and E. Mark intersection on F.
2. Connect F and I. Mark intersection on R_s
3. Connect intersection on R_s with L.
   Value on "r" line shows OHMS/1000 FT. or COPPER EQUIVALENT.

EQUATIONS of CHART

$$R_s = \frac{r L I}{10 E}$$

$$R_s E = F$$

$$GI = F \quad (G \text{ and } R_s \text{ coincident})$$

$$r \frac{L}{10} = G$$